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Postimplantation X-ray parameters predict functional catheter problems in peritoneal dialysis

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Functional catheter problems are a major challenge for peritoneal dialysis (PD) programs. Here we performed a retrospective single-center study of 110 consecutive patients receiving a first PD catheter (swan neck double-cuff Missouri curled catheters, open surgical technique). Using postimplantation X-ray, the following categories were defined: swan neck angle (posterioanterio view (PA): under 45°, 45–90°, over 90°), inclination (angle between intramural part of catheter and horizontal line; lateral view: greater than/equal to 30°, under 30°), and the position of silicone bead relative to spine (PA view: L1-2, L3-4, lower) and catheter tip (PA view: hypogastric, umbilical, subcostal). Covariates included demographics, body size, previous abdominal surgery, and abdominal wall hernias. During a mean follow-up of 36 months, the time to first functional catheter problem was significantly associated with both the swan neck angle and inclination. The need for surgical intervention was significantly associated with inclination only. Technique failure was not associated with any parameter. In multivariate analysis, inclination was the sole variable significantly associated with functional catheter problems (hazard ratio 3.65 [1.98–6.72]) and the need for surgical intervention (hazard ratio 2.86 [1.19–6.88]). Thus, our study defines a set of X-ray variables that predict functional PD catheter problems and can be used for troubleshooting in individual cases as well as for education and internal audit purposes.

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KEYWORDS: catheter; functional catheter problems; peritoneal dialysis; shape memory; swan neck

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A reliable access to the peritoneal cavity is a prerequisite for successful peritoneal dialysis (PD) treatment. Unfortunately, problems with PD catheters are frequently encountered and are identified as one of the issues limiting growth of PD in many centers.[1,2] Increasing numbers of publications on the issue illustrate the growing awareness of this problem, as do the Clinical Practice Guidelines for Peritoneal Access published recently by the International Society of Peritoneal Dialysis (ISPD).[3] The document points to the importance of an adequate ‘access team’, timely referral for catheter placement, reliance on clear protocols for perioperative catheter care, and local expertise governing the choice of method of catheter placement.[4–6] As to which catheter type is to be preferred, the guidelines state that no particular type has been proven to be better than another, although it is recommended to use a catheter of appropriate size.[3,7] Although it is well recognized that the so-called ‘shape memory’ of PD catheters should be respected to prevent catheter migration and malfunction,[8] this is not mentioned in the current ISPD guidelines.

In accordance with Guideline 7, we organized a local audit on the outcome after PD catheter insertion.[3] In addition, we questioned whether baseline abdominal X-ray parameters reflecting adherence to the intrinsic catheter shape and its position could be identified. We investigated whether these parameters could predict functional catheter problems, the consequent need for surgical intervention, and technique failure. The ultimate goal was to establish a novel set of parameters that could be used for troubleshooting in individual cases of functional PD catheter problems as well as for educational and internal audit purposes.

RESULTS

Patient population

Between January 2005 and July 2010, 116 swan neck double-cuff Missouri curled PD catheters were placed in our center. Second catheter placements ($n = 3$) and patients whose medical follow-up was carried out in another center after catheter placement ($n = 3$) were excluded from the present analysis. Baseline demographic and clinical data from the 110 patients included in the analysis are shown in Table 1.

Table 1 | Demographic and clinical data

Variable	Unit	Value
Age	Years	56 ± 16
Gender	Male (%)	64 (58)
Renal diagnosis	dm/eci/gn/in/ms/neo/PKD/other congen (%)	13/35/26/5/10/1/13/7 (12/32/23/5/9/1/12/6)
Diabetes mellitus	Present (%)	24 (22)
CV history	Present (%)	51 (46)
Hypertension	Present (%)	56 (51)
Weight	kg	69 ± 14
BMI	kg/m^2	24 ± 4
CrCl	ml/min	9.3 ± 5.5
Previous abd surgery	Present (%)	41 (37)
	Laparoscopic/open/none (%)	2/39/69 (2/35/63)
	cr/gyn/hb/uro/other/none (%)	9/7/2/15/8/69 (8/6/2/14/7/63)
Hernia	Present (%)	7 (6)
	Inguinal/umbilical/incisional/none (%)	2/4/1/103 (2/3/1/94)
PD modality	CAPD/APD (%)	44/65

Abbreviations: abd, abdominal; BMI, body mass index; CAPD, continuous ambulatory peritoneal dialysis; congen, congenital; cr, colorectal; CrCl, creatinine clearance; CV history, cardiovascular history; dm, diabetes mellitus; eci, e causa ignota; gn, glomerulonephritis; gyn, gynecological; hb, hepatobiliary; in, interstitial nephritis; ms, multisystem; neo, neoplastic; PD, peritoneal dialysis; PKD, polycystic kidney disease; uro, urological.

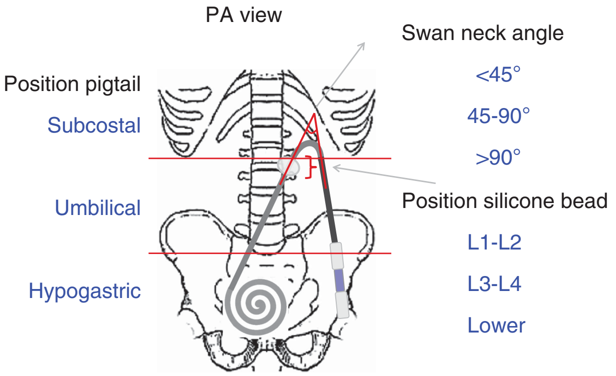

Figure 1 | Schematic representation of the three radiological parameters assessed from plain abdominal X-ray in posterioanterio (PA) view: swan neck angle, position of the silicone bead, and position of the catheter tip. See Materials and Methods section for more details.

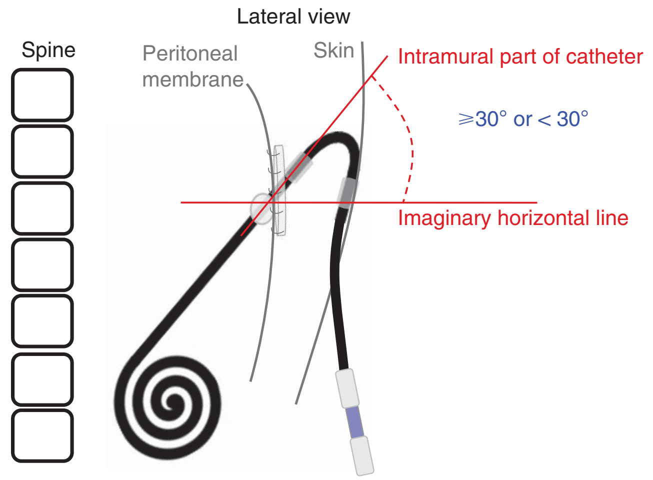

Figure 2 | Schematic representation of the inclination, i.e. angle of the intramural part of the PD catheter with an imaginary horizontal line, as assessed from abdominal X-ray in lateral view. See Materials and Methods section for more details.

Postimplantation X-ray parameters

Parameters assessed from plain abdominal X-ray were swan neck angle, position of the silicone bead and position of the catheter tip in posterioanterio (PA) view, and inclination in lateral view (for detailed definition: see Materials and Methods and Figures 1 and 2). Swan neck angle in PA view was $<45°$ in 57%, 45–90° in 23%, and $>90°$ in 20% of the patients. Inclination in lateral view was $\geqslant 30°$ in 74% and $<30°$ in 26% of the patients. As shown in Tables 2 and 3, patients in whom the catheter 'shape memory' appeared to be least respected (swan neck angle $>90°$, inclination $<30°$) weighed significantly more and had higher body mass index than the other categories. Moreover, there were weak associations of swan neck angle with renal diagnosis (polycystic kidney disease vs. other) and of inclination with history of abdominal surgery. In 25% of the patients, the position of the silicone bead in PA view was at L1-2, in 60% it was at L3-4, and it was lower in 15%. The position of catheter tip in PA view was hypogastric in 63% of the patients, umbilical in 31%, and subcostal in 6%. The silicone bead position was significantly related only with age ($P = 0.01$) and catheter tip position only with history of abdominal surgery ($P = 0.04$).

Outcome parameters

During follow-up from date of implantation until 10/2010 (mean follow-up of 36 ± 17 months), 42 patients (38%) experienced at least one documented clinically overt functional catheter problem. In 21 patients (19%), conservative management with laxatives was unsuccessful and surgical intervention was needed. In 19 of these patients, displacement of the PD catheter was the reason for the malposition found intraoperatively. In four procedures, some adhesions were removed as well, but they were found not to be the cause of the displacement. In one of the two remaining

Table 2 | Demographic and clinical data by category of swan neck angle

Variable	<45°	45–90°	>90°	*P*-value[a]
Age (years)	53 ± 16	57 ± 18	61 ± 14	0.09
Gender (%male)	48	68	73	0.07
Renal diagnosis (%PKD)	17	0	9	0.05
Diabetes mellitus (%)	24	16	23	0.77
CV history (%)	45	44	55	0.70
Hypertension (%)	56	44	45	0.49
Weight (kg)	**66 ± 16**	**66 ± 11**	**74 ± 9**	**0.02**
BMI (kg/m^2)	**24 ± 5**	**23 ± 3**	**26 ± 3**	**0.01**
CrCl (ml/min)	9.5 ± 6.0	9.5 ± 5.0	9.0 ± 5.0	0.95
Previous abd surgery (%)	42	36	27	0.49
Hernia (%)	8	8	0	0.56
PD modality (%CAPD)	42	48	42	0.86

Abbreviations: abd, abdominal; BMI, body mass index; CAPD, continuous ambulatory peritoneal dialysis; CrCl, creatinine clearance; CV history, cardiovascular history; PD, peritoneal dialysis; PKD, polycystic kidney disease.
[a]Kruskal–Wallis test or Fisher's exact test as appropriate—variables that differ significantly between categories are bolded.

Table 3 | Demographic and clinical data by category of inclination

Variable	⩾30°	<30°	*P*-value[a]
Age (years)	54 ± 16	58 ± 17	0.25
Gender (%male)	57	63	0.65
Renal diagnosis (%PKD)	11	15	0.72
Diabetes mellitus (%)	21	26	0.60
CV history (%)	45	52	0.65
Hypertension (%)	52	52	1.00
Weight (kg)	**66 ± 15**	**73 ± 13**	**0.02**
BMI (kg/m^2)	**23 ± 4**	**26 ± 5**	**0.01**
CrCl (ml/min)	9.7 ± 5.6	8.7 ± 4.7	0.58
Previous abd surgery (%)	31	52	0.06
Hernia (%)	4	11	0.19
PD modality (%CAPD)	47	30	0.17

Abbreviations: abd, abdominal; BMI, body mass index; CAPD, continuous ambulatory peritoneal dialysis; CrCl, creatinine clearance; CV history, cardiovascular history; PD, peritoneal dialysis; PKD, polycystic kidney disease.
[a]Kruskal–Wallis test or Fisher's exact test as appropriate—variables that differ significantly between categories are bolded.

intervention cases, the catheter appeared to be wrapped by omentum, whereas in the other (female) patient the catheter position was correct but tubal fimbriae obstructed the side holes. Technique failure was seen during follow-up in 26 patients (23.6%) due to infection ($n=11$), leakage of peritoneal fluid into the pleural cavity ($n=5$), ultrafiltration failure ($n=9$), or a functional catheter problem for which surgical intervention was refused by the patient ($n=1$).

In univariate survival analysis using radiological, demographic, and clinical parameters as explanatory variables, only swan neck angle ($P=0.02$) and inclination ($P<0.001$) were found to be associated with time to first functional catheter problem. Need for surgical intervention was associated with inclination only (univariate $P=0.02$), whereas definitive technique failure was not significantly associated with any of the parameters studied. Figure 3 shows the unadjusted Kaplan–Meier survival curves of time to first functional catheter problem (A) and time to surgical intervention (B) for patients with inclination ⩾30° and <30°.

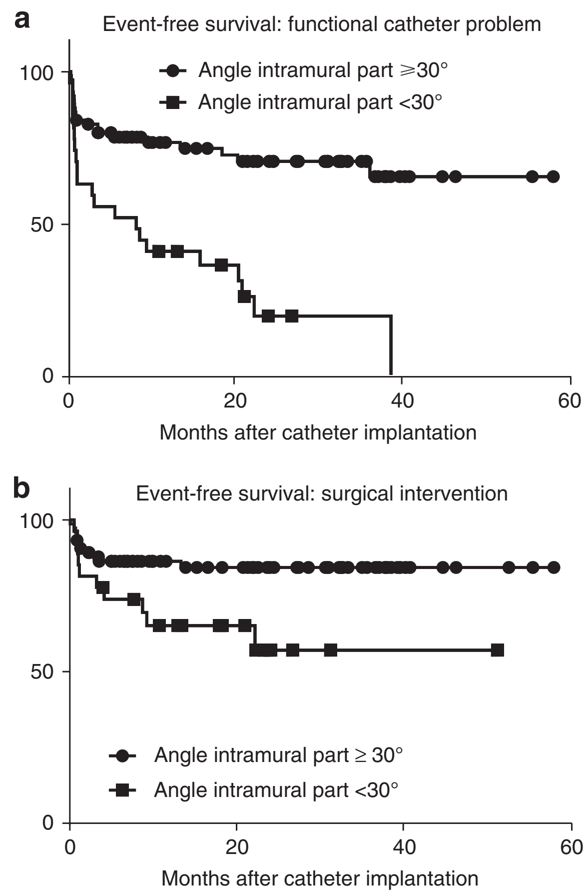

Figure 3 | Functional PD catheter outcome according to angle of the intramural part. Kaplan–Meier survival curves of time to first functional catheter problem (**a**) and time to surgical intervention (**b**) for patients with ⩾30° and <30° angle of the intramural part of the PD catheter.

Table 4 | Log rank *P*-values for association of the radiological parameters with end points

End point	Swan neck angle	Inclination	Position of catheter tip	Position of silicone bead
Time to first functional catheter problem	**0.02**	**<0.001**	0.12	0.67
Time to surgical intervention	0.21	**0.02**	0.45	0.94
Time to technique failure	0.09	0.08	0.23	0.34

Significant *P*-values are in bold.

In Table 4, the log rank *P*-values of all four radiological parameters are shown for each of the three end points.

Using a multivariate approach for developing a Cox proportional hazards model explaining the time to first functional catheter problem, the following parameters met the $P<0.2$ criterion for inclusion in the best subset selection step: swan neck angle, inclination, position of the catheter tip, gender, weight, and PD modality. In the final backward model, however, only the inclination was significantly associated with the end point: <30° vs. ⩾30°, hazard ratio 3.65 [1.98–6.72] ($P<0.001$).

Similarly, after initial introduction of creatinine clearance, PD modality, and inclination in the multivariate model, only the latter variable retained significance for the association with time to surgical intervention: $<30°$ vs. $\geqslant 30°$ hazard ratio 2.86 [1.19–6.88] ($P=0.02$).

Not surprisingly, based on the univariate analysis, none of the studied variables were retained in a model explaining the time to technique failure.

DISCUSSION

The main and novel finding of this single-center retrospective study of 110 swan neck double-cuff Missouri curled PD catheters is that radiological parameters, evaluated from plain abdominal X-rays taken 2 days after catheter placement, predict functional catheter problems and the need for surgical intervention. In particular, the inclination of the catheter through the abdominal wall was independently associated with the occurrence of these outcomes in a multivariate analysis including variables reflecting demographics and comorbidity, body size, history of abdominal surgery, and the presence of abdominal wall hernias. Although not being retained in multivariate analysis, the radiological appearance of the swan neck angle was also associated with the occurrence of clinically overt functional catheter problems. Our study is the first to use these newly defined radiological parameters for PD catheter evaluation. However, the findings may not be surprising, given the importance of adherence to the so-called 'memory' of PD catheters. Although the swan neck configuration of PD catheters was originally developed to overcome the problems caused by the straight 'shape memory' of the Tenckhoff and Toronto Western Hospital catheters,[8] the swan neck double-cuff Missouri curled catheter clearly has a 'memory' too. Indeed, the inclination of the catheter in lateral view and the swan neck angle in PA view do reflect the agreement between the actual catheter position and its intrinsic shape. One can easily imagine that putting a catheter in place without meticulously respecting its intrinsic 'shape memory', may force the catheter tip to move out of the pelvis.

Two other radiological variables were not associated with any of the outcome parameters. The position of the silicone bead relative to the spine was chosen in order to evaluate whether a 'too high' or 'too low' catheter position would influence its function. One of the factors explaining the negative findings may be that the radiological score is based on an X-ray taken in the standing position, whereas all patients carry out their PD exchanges while sitting or being supine. The position of the catheter tip in PA view was not associated with any of the outcomes either. In our opinion, this can be explained by the fact that the 2-day postoperative X-ray is just a snapshot taken at a moment before the actual start of PD treatment. Moreover, taking into account the lively peristalsis of the small intestines, the catheter tip position is not constant over time.

In contrast to the associations found with clinically overt functional catheter problems and time until the need for surgical intervention, none of the studied variables was significantly associated with technique survival. There were marginal associations of swan neck angle ($P=0.09$), inclination ($P=0.08$), and body mass index ($P=0.09$) with this outcome in univariate analysis, but none in multivariate analysis. This can be explained by the fact that surgical intervention was successful in most cases. Indeed, as per our surgical protocol, a diagnostic laparoscopy was performed in these instances, followed by fixation of the straight part of the catheter to the abdominal wall. Only one of the technique failures was motivated by persistent functional catheter problems, due to the refusal of the patient to undergo surgery. One might argue that peritoneo–pleural leakage, motivating technique failure in five cases in our series, may have caused a clinical picture that fitted well within our definition of functional catheter problems and thus may have led to overdiagnosis of the latter. In three of the patients, however, a gradually developing unilateral pleural effusion was noted by X-ray evaluation because of progressive dyspnea without the patient experiencing overt outflow problems or negative ultrafiltration with icodextrin. In the two remaining patients, pleural leakage occurred after surgical repositioning of the catheter.

Previous intra-abdominal surgery and the presence of hernias might theoretically challenge good catheter function.[9–11] None of these variables were associated with any of the outcomes in our study, let alone the particular type of abdominal surgery or hernia (data not shown). This is in accordance with other published data.[9,12] Similarly, there was no significant association of the outcomes with weight or body mass index, although the available literature shows equivocal findings in this respect.[13–15] However, as can be judged from Tables 2 and 3, swan neck angle category was associated with body size, and inclination was related to body size and history of abdominal surgery. From this, it can be interpreted that proper positioning of a PD catheter in the abdominal wall is a greater challenge in obese patients and patients with a history of abdominal surgery.

We feel that our findings can be valuable in particular clinical cases with functional catheter problems where surgical intervention is planned. If in such a case both swan neck angle and inclination are 'unfavorable' and no other reason for the dysfunction is found intraoperatively (adhesions, hernias, and so on), it might be better to place a new catheter than to fix the catheter to the anterior abdominal wall. In our experience, the latter approach is not a good solution and the functional problems will often recur. A controlled study would be needed to formally confirm this. Beyond the individual cases, however, the major application of our novel X-ray evaluation may be for educational purposes. Indeed, it might help to increase PD access teams' awareness of the crucial elements for good PD catheter function. Finally, the X-ray scoring may be incorporated in the internal audit procedure suggested by the ISPD guidelines,[3] as it offers information on potentially modifiable aspects of the catheter placement techniques.

Some limitations of our study need to be addressed. First, the retrospective character of this patient file-based survey may have led to an underestimation of the number of functional catheter problems. Indeed, minor problems may not have been reported in the medical files. It is not clear whether prospective collection of data using clear definitions would have generated different results. However, the surgical intervention data presented here are not subjected to this potential bias. Moreover, the unbiased end point 'need for surgical intervention' was also evaluated in a validation set of 41 patients in whom a first PD catheter was placed between 5 October 2010 and 22 February 2013. Only three of these patients needed a reintervention because of mechanical catheter problems (7%), which is clearly less than during the preceding period from 2005 to 2010 (19%). Unfortunately, in three of the patients (not those who needed reintervention) the X-ray images didn't allow proper interpretation of swan neck angle or inclination because of superposition or inadequate scope of the view. From the 38 evaluable X-rays, swan neck was $>90°$ only in two (5% vs. 20% 2005–2010) of the patients and 45–90° in four patients (10% vs. 23% 2005–2010). Inclination in the abdominal wall was $<30°$ in only four patients (10% vs. 26% 2005–2010). As such, the proportions of 'unfavorable' X-ray parameters were much lower than during the preceding period. Relating the X-ray parameters to the outcome 'need for surgical intervention' in this second cohort showed a significant association for the inclination again (log rank $P = 0.03$). In our view, however, the main message from the findings in the two consecutive cohorts is that reviewing the X-rays in 2010 and the consequent open and constructive interaction between the surgery and nephrology team has resulted in a major improvement in our PD program. The data also support our conviction that the technical aspects of the procedures need to be stressed, rather than focusing on the individuals performing them. Indeed, the proportion of swan neck angle $>90°$ and inclination $<30°$ varied significantly between surgeons. However, introducing the 'surgeon' variable in the multivariate outcome models by allowing it to be included in the best subset selection step did not change the results at all: radiological variables clearly surpass the predictive power of the 'surgeon' variable (data not shown).

Second, although the use of only one catheter type in our study strengthens its homogeneity, there may be a problem of generalizability of the results. The question whether radiological parameters may also be of help when using other catheter types needs to be addressed. It is of note, however, that swan neck catheters are the second most commonly used PD catheters worldwide (26%) with higher proportions in United States (36%) and Europe (49%).[16] Moreover, the downward intramural trajectory of PD catheters is of importance for proper functioning of any type of catheter and this parameter ('inclination') was found to be most predictive in our study. Of note, this finding corroborates the original recommendations of Tenckhoff and Schechter[17] that a PD catheter's coil should be placed against the parietal peritoneum for optimum drainage. We acknowledge, however, that the intra-peritoneal bead and the obliquely positioned felt disc are particular features of the Missouri variant of PD catheters, which probably aggravates the functional implications of an 'unfavorable' angle of the intramural catheter part.

In conclusion, this study defines a novel set of X-ray parameters for prediction of functional PD catheter problems. These parameters can be used for troubleshooting in individual cases as well as for educational and internal audit purposes. Furthermore, our findings confirm that adherence to the catheter 'shape memory' is important for proper PD catheter function.

MATERIALS AND METHODS

Study design

Single-center retrospective study of all patients who had their PD catheter implanted between January 2005 and July 2010. Second PD catheter placements and patients whose medical follow-up was performed in another center after catheter placement were excluded from the study.

Catheter type and method of insertion

Only swan neck double-cuff Missouri curled catheters (Argyle Swan Neck Curl Cath Missouri Peritoneal Dialysis Catheter, manufactured by Covidien, Dublin, Ireland) were used,[8] all placed by a standardized open surgical technique under general anesthesia. Using this technique, the anterior fascia of the rectus sheath is opened through a 3–5 cm vertical paramedian incision and the rectus abdominis muscle vessels are split exposing the posterior layer of the rectus sheath. A small incision is then made in the posterior rectus sheath and peritoneum. The catheter, placed over a long straightening stylet, is inserted in the peritoneal cavity and placed in the rectovesical or rectovaginal pouch in men or women, respectively. After the correct position of the catheter tip is checked by radioscopy, the peritoneum is closed using a nonabsorbable purse string suture on the posterior rectus sheath placed between the silicone bead and the felt disk. As such, the felt disk is placed outside the peritoneal cavity, secured by four extra sutures to avoid later dislocation and then covered by the rectus muscle. Next, to test the functioning of the catheter, ~1000 ml dialysate fluid is infused under gravity, whereas the peritoneal entrance site is checked for leakage. The dialysate fluid is allowed to drain and inspected for evidence of hemoperitoneum or any contamination. The extraperitoneal part of the catheter is then carefully positioned aiming to respect the course and the pre-formed angle of the swan neck by creating a subcutaneous pouch. Using a tunneling trocar with the same diameter as the catheter tubing, a tunnel is created to place the distal part of the catheter subcutaneously. The distal cuff is placed 2 cm from the exit site. After final hemostasis, the anterior rectus sheath and skin are closed, ensuring not to obstruct the catheter, whereas the function of the catheter is checked a last time.

Definition of postimplantation X-ray parameters

The 'shape memory' of swan neck catheters requires two features to be taken into account for good function: (1) swan neck angle $<45°$ and (2) correct inclination of the intramural part of the catheter through the abdominal wall (running downward from outside to inside, angle with imaginary horizontal line at least 30°). We interpreted this from plain abdominal X-rays taken in the standing position 2 days after catheter implantation in all patients and categorized as follows: swan neck angle in PA view ($<45°$, 45–90°, $>90°$) and inclination, i.e. angle between intramural part of the catheter and an imaginary horizontal line, in lateral view ($\geqslant 30°$, $<30°$). In addition, we evaluated the position of the silicone bead relative to the spine (L1-2, L3-4, lower) and the position of the catheter tip (hypogastric, umbilical, subcostal zone) in PA view. (See Figures 1 and 2.)

Demographic and clinical data

Patient age, gender, renal diagnosis, comorbidity (diabetes, hypertension, cardiovascular history), anthropometry (weight, body mass index), and creatinine clearance (based on 24 h urine measurement) at start of PD were retrieved from the medical files, as well as the principal treatment modality (continuous ambulatory vs. automated PD (CAPD vs. APD)).

Furthermore, files were checked for a history of previous abdominal surgery. If so, the type of surgery was categorized as 'laparoscopic vs. open' and as 'hepatobiliary, gynecological, urological, colorectal, or other'. If there was more than one abdominal surgical procedure before catheter placement, the most invasive one was considered relevant for the outcome studied and reported in the database. Finally, the presence of abdominal wall hernias at the time of catheter placement and the type of hernia (incisional, umbilical, inguinal) were reviewed.

Outcome parameters

Three outcomes were studied: the occurrence of clinically overt functional catheter problems, the consequent need for surgical intervention, and definitive PD technique failure (censored for patient death, loss of follow-up, recovery of kidney function, and renal transplantation). For the outcome 'clinically overt functional catheter problem' one or more of the following items mentioned in the patient files were considered: troublesome inflow of dialysate, troublesome outflow of dialysate, and negative ultrafiltration with 8 h dwell of icodextrin.

Investigators were blinded for X-ray parameters when retrieving demographic, clinical, and outcome data from the patient files.

Statistical analysis

Continuous variables are expressed as mean ± s.d. and categorical variables as percentages of the total number of patients. For comparisons between groups, the Mann–Whitney *U*-test, the Kruskal–Wallis test (continuous variables), or the Fisher's exact test (categorical variables) were used. In order to evaluate the influence of baseline variables on the outcomes, time to first event analysis was performed using Cox proportional hazards statistics and relative risks were expressed as Hazard Ratios. The Kaplan–Meier method was used to estimate cumulative incidence of the different end points. Data were censored in case of patient death, loss of follow-up, recovery of kidney function, transplantation, or at the end of the observation period (10 October 2010). Additional censoring for technique failure was performed in the analysis of functional catheter problems and surgical intervention. Variables that affected the outcome ($P<0.2$) were included in a multivariate analysis. A selected subset of variables (by a backward elimination on $P<0.2$) was entered in a backward elimination procedure on $P<0.05$ to define the best model explaining the outcome. Proportionality assumption was tested by using the 'proportionality test' statement within the PHREG procedure and by inspection of log(-log(survival)) curves. Hazard ratios are given with their 95% confidence intervals. P-values <0.05 were considered significant. The SAS version 9.3 (SAS Institute, Cary, NC) software program was used for the statistical analysis.

DISCLOSURE

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